

Hypoxic Training for Enhancement of Performance

Evidence-based or magical thinking ?

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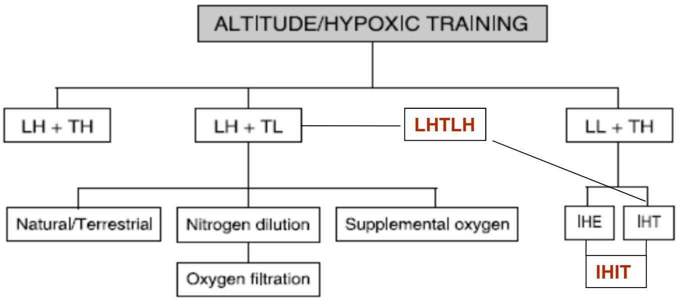

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Why ?

Underlying mechanisms
Erythropoiesis vs. non-hematological factors

How ?

LHTH vs. LHTL vs. IHE/IHT (IHIT and LHTLH)
Altitude x duration / intensity

HH (terrestrial) vs NH (simulated)

for Who ?

Endurance vs. "lactic" vs. intermittent sports

When ?

Periodization in the yearly program

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Normobaric Hypoxia (NH)
vs.
Hypobaric Hypoxia (HH)

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Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

HH (Leukerbad, Switzerland)

NH (Prémanon, France)

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Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

Combinations of barometric pressure (PB) and inspired fraction of oxygen (F_IO_2) that result in any inspired pressure of oxygen (P_IO_2) less than a normoxic value of 150 mmHg is by definition hypoxic (*Conkin and Wessel 2008*).

Altitude (m)	Pb (mm/Hg)	PO_2 (mm/Hg)	PAO_2 (mm/Hg)	$FO_{2\ normalisée}$ (%)
2 000	596	125	115	16,44
2 100	589	123	114	16,24
2 200	582	122	112	16,04
2 300	575	120	111	15,84
2 400	567	119	109	15,64
2 500	560	117	108	15,45
2 600	553	116	106	15,25
2 700	546	114	105	15,06
2 800	540	113	103	14,87
2 900	533	112	102	14,69
3 000	526 →	110	100	← 14,50
3 100	519	109	99	14,32
3 200	513	107	98	14,14
3 300	506	106	96	13,96

(Millet & Schmitt, 2011).

PO_2 can be perfectly matched between NH and HH

Inducing similar acute responses ? / long-term adaptations ?

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Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

Recent evidences suggest that the physiological responses to normobaric and hypobaric hypoxia are <u>different</u>.

1. Ventilatory responses
2. Fluids
3. Pre-acclimatization and AMS severity
4. Performance
5. NO metabolism
6. Oxidative stress
7. Postural stability

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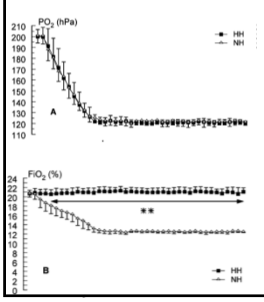
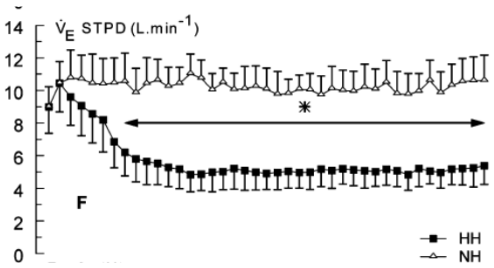
Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

1. Ventilatory responses

- Ventilation seems lower in HH than NH (*Loeppky et al. 1997; Savourey et al. 2003*)
- P_AO_2 is slightly higher in NH than HH, especially with hyperventilation.
- Specific adaptation of a lower tidal volume and a higher respiratory frequency.
- Trend to lower $P_{ET}O_2$ and $P_{ET}CO_2$ values in HH.
- Overall, this might come from a alveolar physiological dead space higher in HH.





Rest 40-min HH or NH ; PO2 = 120 hPa (4500 m).
(*Savourey et al. 2003*)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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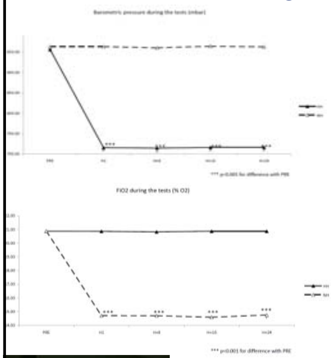
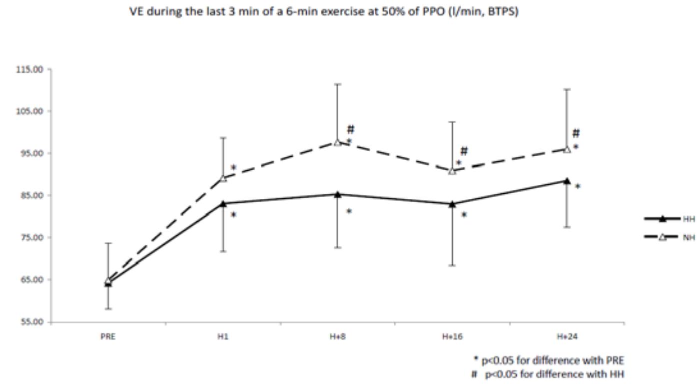
1. Ventilatory responses

This was supported by our preliminary study (*Faiss et al. 2012*) where ventilation during submaximal (50% PPO) exercise was lower in HH





24-h HH or NH (3000 m).

(*Faiss et al. 2012*)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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2. Fluids

- PB can modify the fluid circulation (e.g., pulmonary lymph) and the trans-alveoli-capillary membrane flux (*Levine et al. 1988*).
- This might induce a larger pulmonary vasoconstriction in HH and modify the O_2 diffusion by decreasing the pressure gradient.
- PB might influence also the N_2 and O_2 concentration in the cerebrospinal fluid and therefore change partly the central regulation of ventilation (*Conkin and Wessel 2008*).

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Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

3. Pre-acclimatization and AMS severity

Pre- Acclimatization in HH

3-week of IAE (intermittent altitude exposures : 4 h.day, 5 d.wk, 4300 m).

30 h exposure to 4300 m altitude-equivalent (barometric pressure=446 mmHg)

- The severity of AMS decreased
- Resting $P_{ET}CO_2$ (mmHg) decreased (i.e. increase in ventilation)
- In conclusion… an effective alternative to chronic altitude residence for increasing resting ventilation and reducing the incidence and severity of AMS.

(*Beidleman et al. 2003*)

Pre- Acclimatization in NH

7.5 h each night for 7 nights in NH (F_IO_2: from 16.2 to 14.4%; 3100 m) or « sham »

5 days at HH (4,300 m)

- Only sleep $Sa(O_2)$ was higher and only AMS upon awakening was lower in the NH than sham
- …had no impact on AMS or exercise performance for the remainder of each day.

(Fulco et al. 2011)

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Table 2. Evidence and Strength of Induced Acclimatization

Ref	Short Title	Acclimatization Strategy	PetCO₂ (mmHg)	SaO₂ (%)
		Compared from the Beginning to the End of the Acclimatization Strategy		
(20; 21)	Benchmark (After Prolonged Exposure)	Highly Effective	Decreased +++++	Increased +++++
(2; 3)	IAE 15	Highly Effective	n/a	Increased +++++
(4)	IAE 7	Effective	n/a	Increased +++
(1; 10)	Staging	Effective	Decreased +	Increased
(14)	MAR	Highly Effective	Lower +++++	Higher +++++
(9)	NH (Sleep)	Effective (NH Treatment)	Decreased +++	n/a
		None (Sham)	No Change	n/a
(5; 19)	NH (Awake)	Highly Effective (NH Treatment)	Decreased[b] +	Increased[b] +++++
		None (Sham)	No Change	No Change

[a]Measured at 2200 m and compared to SLR values at 2200 m; [b]Measured at 4500 m equivalent (90 mmHg); +++++ = ≥4 mmHg reduction in $PetCO_2$, or an increase of ≥5% in SaO_2; +++ = 3 or 4 mmHg reduction in $PetCO_2$, and a 3 to 5% increase in SaO_2; + = 1 to 2 mmHg reduction in $PetCO_2$, and an 1 to 2% increase in SaO_2. "Highly Effective" = +++++ for either $PetCO_2$ or SaO_2; "Effective" = +++ for either $PetCO_2$ or SaO_2. n/a = not assessed.

To our view, the most striking and novel finding arising from Fulco et al. is the very low (or lack of) transfer of the benefits induced by the NH-acclimatization to the HH condition: When transported to 4300 m (HH), subjects who were pre-acclimatized in NH had a minimal benefit (e.g., no or <1 mmHg decrease in $P_{ET}CO2$ or AMS prevalence of 50%-64% instead of 80-100% in non-acclimatized subjects).

The ventilatory acclimatization can be effective in NH, but not in HH, and that the light ventilatory and AMS benefits retained in HH for the NH pre-acclimatized groups did not translate to performance benefits.

(Millet et al. ESSR 2012)

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Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

4. Performance

Meta-analysis show that LHTL in HH (e.g. Levine et al.) induces larger increase in sea-level power output than LHTL in NH (e.g. AIS)

Table II. Meta-analysis of effects on sea-level mean power output following adaptation to hypoxia experienced in studies with various protocols of natural and artificial altitude. Effects of mean and enhanced protocols are those predicted for controlled trials and maximal tests. Effects in parentheses are unclear (>5% chance of enhancement and >5% chance of impairment); otherwise **bold** indicates ≥50% chance of enhancement, *italic* indicates ≥50% chance of impairment, and plain font indicates ≥50% chance of trivial effect. These probabilistic outcomes are computed with reference to a smallest important change of 1%

Effect	Natural altitude protocols		Artificial altitude protocols			
	live-high train-high	live-high train-low	live-high 8–18 h/d, continuous, train-low	live-high 1.5–5 h/d, continuous, train-low	live-high <1.5 h/d, intermittent, train-low	live-low train-high 0.5–2 h/d
Effect of mean protocol[a] (%); ±90% CL[b]						
Elite	(1.6; ±2.7)	**4.0; ±3.7**	(0.6; ±2.0)		(0.2; ±1.8)	
Subelite	(0.9; ±3.4)	**4.2; ±2.9**	**1.4; ±2.0**	(0.7; ±2.5)	**2.6; ±1.2**	(0.9; ±2.4)
Effect of enhanced protocol[c] (%); ±90% CL						
Elite	**5.2; ±4.1**	**4.3; ±4.1**	(4.0; ±5.5)		(1.2; ±2.5)	
Subelite	**4.5; ±4.1**	**4.6; ±3.3**	**4.8; ±5.3**	**3.5; ±3.5**	**3.6; ±2.1**	**6.8; ±4.9**
Study characteristics changed by +1 SD or −1 SD for enhanced protocol	+Altitude −Days exposure +Test day	−Altitude −Test day	+Altitude +Hours hypoxia −Days exposure	−Altitude −Test day	+Exposure ratio −Test day	−Altitude −Train intensity +Days exposure +Test day

(Bonetti and Hopkins 2009)

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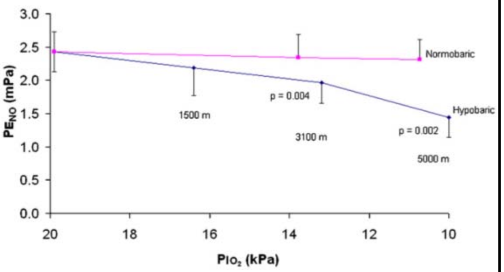
Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

5. NO metabolism

- NO exhaled is lower in HH than in NH (*Hemmingsson and Linnarsson 2009*).
- This would come from a higher diffusion from the upper tracts to the alveoli then to hemoglobin in HH.
- The level of NO recapture by the blood compartment would be higher in HH.
- It is unclear how and if this mechanism is related to the higher benefits to train in « real altitude » than in « simulated altitude » (*Kayser 2009*).

- Relationships between decrease in NO, pulmonary arterial pressure and the pulmonary oedema risk (*Busch et al. 2001; Duplain et al. 2000*).
- The decrease in exhaled NO comes from the epithelial cells of the respiratory tractus.

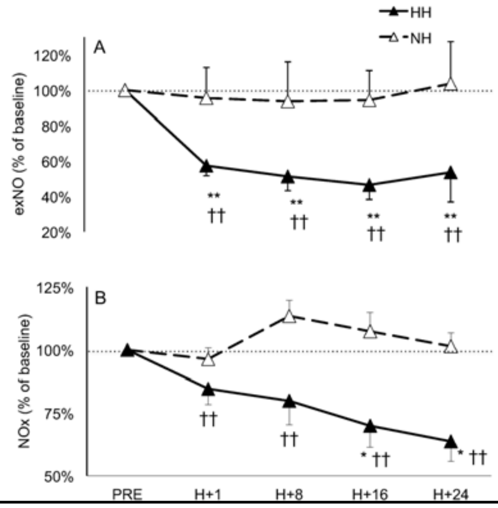


(Hemmingsson & Linnarsson, 2009)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

5. NO metabolism

- This was supported by our study (*Faiss et al. 2012*) where exhaled NO was lower in HH
- Similarly, NOx decreased over 24h in HH (-36%, p<0.05) but was stable in NH



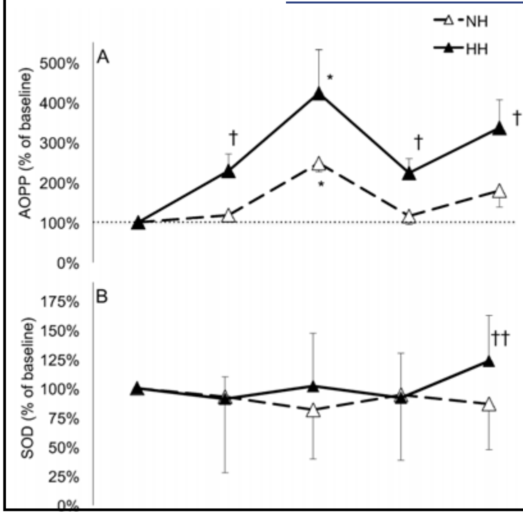
24-h HH or NH (3000 m).

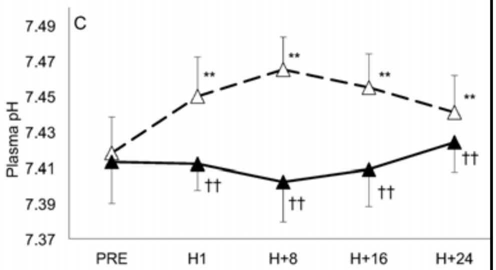
(*Faiss et al. 2012*)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

6. Oxidative stress

- In our preliminary study (*Faiss et al. 2012*), we show that some markers of the oxidative stress increased more in HH and in NH.





** p<0.01, * p<0.05 for difference with PRE
†† p<0.01, † p<0.05 for difference with NH

24-h HH or NH (3000 m).

(*Faiss et al. 2012*)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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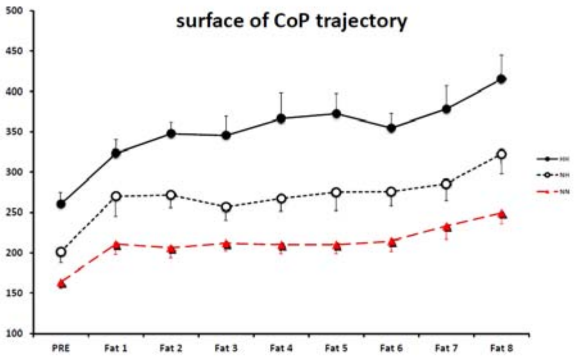
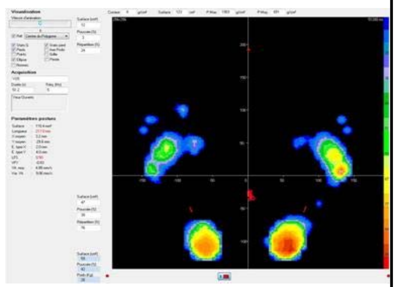
7. Postural stability

- HH deteriorated postural stability in the antero-posterior plane, for the variance of speed and the surface of CoP, whereas no difference was observed between NH and NN. **..**
- **…suggest that hypobaria instead of hypoxia *per se* plays an important contribution to the altered balance classically reported in altitude**



…and increase the fatigue-related altered balance (Degache, Roy et al, ..)



NN or NH or HH (1700 and 3000 m).

(*Degache et al. 2012*)

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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Evidences that NH and NH are NOT similar and induce different responses

Preliminary data from our group suggest that oxidative/nitrosative stress induced by hypoxia differ between normobaric and hypobaric exposure.

Oxidative/nitrosative stress plays a major role in the cardiovascular regulation, endothelial function, sympathetic activation, neuromuscular fatigue and therefore endurance exercise responses

We hypothesized that different magnitude of hypoxia-induced oxidative/nitrosative stress may play a role in the different physiological responses to hypoxia between normobaric and hypobaric exposure

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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With the recent development of hypoxic training methods combining "real" (HH) and "simulated" (NH) altitude (*Millet et al. 2010*), it is important to further investigate if HH and NH induce noticeable different physiological responses.

We hypothesize that the benefits re. systemic adaptations and/or performance of the HH methods are larger than the NH methods.

Consequences in term of periodization ?

Normobaric Hypoxia (NH) vs. Hypobaric Hypoxia (HH)

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Current investigations

HH (JungFrauHoch, 3600 m) vs. NH and NN (hypoxic chamber) during 30h

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International Altitude Training Sites

(< 2000 m.)

Altitude training site	Country	Elevation (m)
Prémanon	France	1 200
Thredbo Alpine Training Center	Australia	1 365
Crans Montana	Switzerland	1 500
Albuquerque, New Mexico	USA	1 525
Fort Collins, Colorado	USA	1 525
Potchefstrom	South Africa	1 550
Snow Farm	New-Zealand	1 560
Davos	Switzerland	1 560
Issyk-Kull	Kirgizistan	1 600
Machakos	Kenya	1 600
Denver, Colorado	USA	1 610
Medeo	Kazakstan	1 691
Tamga	Kirgizistan	1 700
Pretoria	South Africa	1750
Boulder, Colorado	USA	1 770
Ifrane	Morocco	1 820
St. Moritz	Switzerland	1 820
Nairobi	Kenya	1 840
Font Romeu	France	1 850
Colorado Springs, Colorado	USA	1 860
Kunming	China	1 895
Pontresina	Switzerland	1 900
Zetersfeld/Linz	Austria	1 950
Kapsabet	Kenya	1 950
Piatra Arsa	Romania	1 950
Tzahkadzor	Armenia	1 970

(> 2000 m.)

Belmeken	Bulgaria	2 000
Kesenoy-Am	Russia	2 000
Nandi Hills	Kenya	2 000
N'gong Hills	Kenya	2 000
Sestriere	Italy	2 035
Eldoret	Kenya	2 100
Flagstaff, Arizona	USA	2 134
Kipkabus	Kenya	2 200
Los Alamos, New Mexico	USA	2 208
Quito	Ecuador	2 218
Iten	Kenya	2 300
Alamosa, Colorado	USA	2 300
Mexico City	Mexico	2 300
Sierra Nevada/Granada	Spain	2 320
Nyahururu	Kenya	2 350
Addis Ababa	Ethiopia	2 400
Park City, Utah	USA	2 440
Mammoth Lake, California	USA	2 440
Bogota	Colombia	2 500
Toluca	Mexico	2 700
La Paz	Bolivia	3 100

(adapted from Wilber, 2004)

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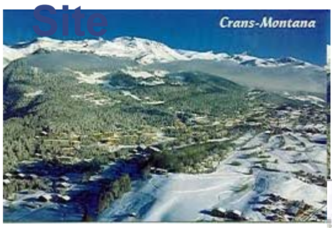
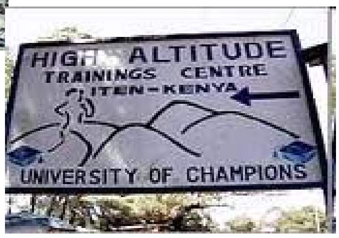
Site





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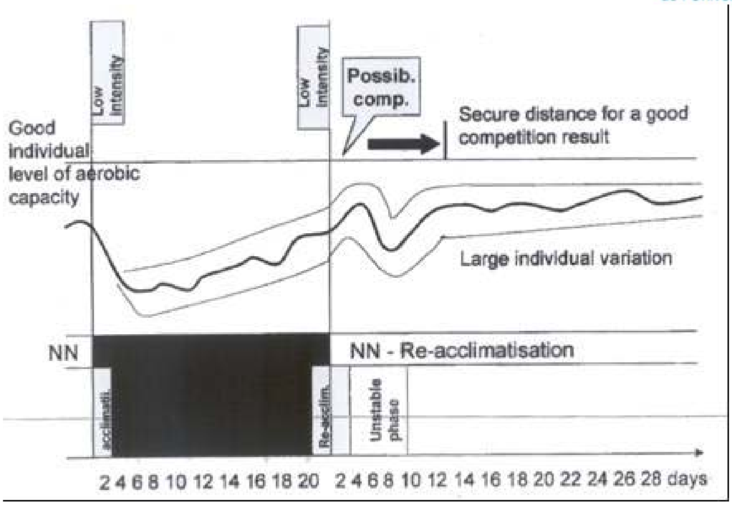
Living high – Training high

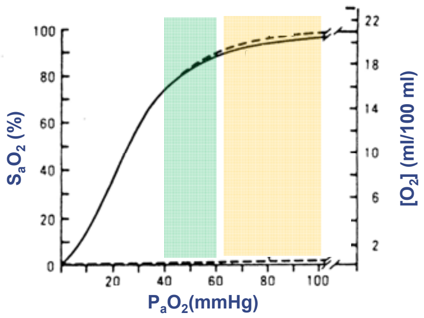
Altitude training					
21 Days					
1---2---3---4---5---6--7--8--9--10---11---12---13---14---15---16---17---18---19---20---21					
6 MICROCYCLES					
2 Days	4 Days	4 Days	4 Days	4 Days	3 Days
4 Phases					
2 Days Accli – mati - sation	7 Days General training period - Aerobic training - Sprint training - Strength training		10 Days Specific training period - Aerobic training - Anaerobic training - Sprint training - Race pace training - Strength training		2 Days Recupe - ration

Living high – Training high



Fuchs & Reiss. Höhentraining,1990.

LHTH - Optimal altitude for erythropoiesis ?



oxyhemoglobin dissociation curve

Owing to the flat shape of the oxyhemoglobin dissociation curve above 60 mmHg, changes in P_aO_2 may not have much effect on S_aO_2.

P_aO_2 values below 60 mmHg are reached from altitudes of about 2500 m (*Anchisi et al., 2001)*

Optimal altitude for LHTH are therefore slightly below this altitude (2200-2500 m)

due to the combined effect of altitude- and exercise-induced desaturation (Woorons et al. 2007)

LHTH - Return to sea-level

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1. a *positive* phase (2 to 4 days)
   - hemodilution
   - ventilatory adaptations

2. a *negative* phase (5-12/15 days) of progressive reestablishment of sea-level training volume and intensity.
   - altered energy cost
   - neuromuscular loss of adaptation

3. a third *positive* phase (after 15 to 21 days) characterized by a *plateau in fitness*.
   - **increase in O_2 transport** (? neocytolysis)
   - delayed HVR benefits
   - increased economy

4. A FOURTH *negative* phase (30-35 days) ?

(Bonetti and Hopkins 2009 ; Issurin 2007)

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Base training

BASE MODEL : combination between hypoxic training and normoxic training in the preparatory training period

Hypoxia		■	■	■					
Normoxia					■	■	■	■	■
Training load	Very high						■	■	
	High			■			■	■	
	Medium		■	■		■	■	■	
	Low	■	■	■		■	■	■	
	Very low	■	■	■	■	■	■	■	■
Training intensity		int ≤ VT1 strength training	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	int ≤ VT1	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	Recovery int ≤ VT1
Days		7	7	7	7	7	7	7	7

Millet et al. 2010

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Competition in altitude

HYPOXIC TRAINING MODEL : to prepare a period of competitions in altitude									
Hypoxia		■	■	■			■	■	■
Normoxia					■	■			
Training load	Very high			■					■
	High			■					■
	Medium		■	■		■	■		■
	Low	■	■	■		■	■		■
	Very low	■	■	■	■	■	■	■	■
Training intensity		int ≤ VT1 strength training	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	int ≤ VT1	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	Short recovery int ≤ VT1	Compet. period in altitude
Days		7	7	7	7	6	5	2 to3	1 to 15

Millet et al. 2010

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Competition at sea-level

HYPOXIC TRAINING MODEL : to prepare a period of competitions at sea level									
Hypoxia		■	■	■					
Normoxia					■	■	■	■	■
Training load	Very high			■					■
	High			■			■		■
	Medium		■	■		■	■		■
	Low	■	■	■		■	■		■
	Very low	■	■	■	■	■	■	■	■
Training intensity		int ≤ VT1 strength training	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	int ≤ VT1	int ≤ VT1 int ≤ VT2 strength training	int ≤ VT1 int ≤ VT2 int ≤ MAP strength training	Short recovery int ≤ VT1	Compet. period at sea level
Days		7	7	7	7	6	5	2 to3	1 to 15

Millet et al. 2010

LHTH

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Why ?

Erythropoiesis
Increase in hb and red blood cell mass

How ?

Altitude : > 1800 - 2200 – 2500 m
Duration : min 3-weeks. Up to 4 weeks

for Who ?
When ?

Endurance : 2-4 times a year
"lactic" : once during winter training
Intermittent: LMTM for general fitness

LHTH

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International Olympic Committee consensus statement on thermoregulatory and altitude challenges for high-level athletes

MF Bergeron,[1,2] R Bahr,[3] P Bärtsch,[4] L Bourdon,[5] JAL Calbet,[6] KH Carlsen,[7–9] O Castagna,[5] J González-Alonso,[10] C Lundby,[11] RJ Maughan,[12] G Millet,[13] M Mountjoy,[14–16] S Racinais,[17] P Rasmussen,[11,18] DG Singh,[19–21] AW Subudhi,[22] AJ Young,[23] T Soligard,[24] L Engebretsen[24]

On the basis of the present literature, it is impossible to provide a clear-cut conclusion concerning LHTH and potential gains in performance at sea level

(1) LHTH may increase sea level performance in some, but not all, individuals.
(2) based on current knowledge it appears that athletes should live at an altitude at or above 2000 m to confer potential benefits from altitude training
(3) the duration of exposure should not be less than 3–4 weeks.

We would highly recommend scientist with an interest in LHTH conduct their studies using elite athletes with controlled designs, since a major limitation in most studies is the inclusion of trained subjects rather than elite athletes.

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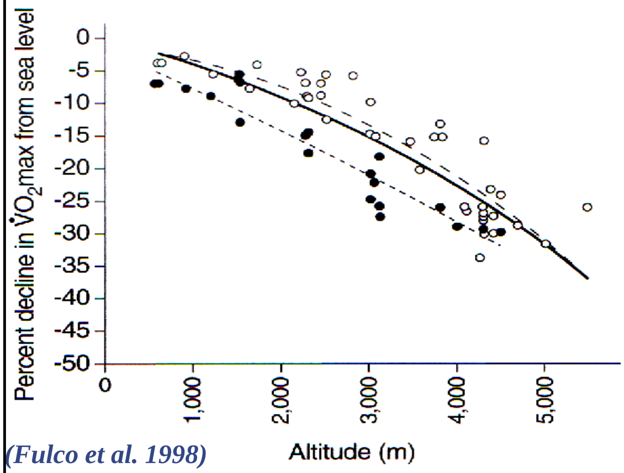

(Fulco et al. 1998)

Altitude training:

- ↘ **Training intensity**
- ↘ **Deterioration of muscular functions**
- ↘ **Immune function**

(Bailey et al. 1998, Levine 1992)

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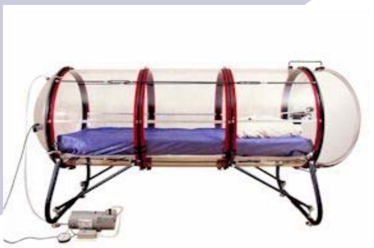
Living high – Training low

HYPOXIC SITE	
Premanon, XC national-center, France	*O2-extracted*
Japanese Sport Institute, Japan	*?*
BSU, Beijing, China	*O2-extracted*
Vuokatti, Finland	*Nitrogen*
Runaway Bay centre, Gold Coast, Australia	*?*
AIS, Canberra, Australia	*Nitrogen*
Aspetar, Doha, Qatar	*O2-extracted*



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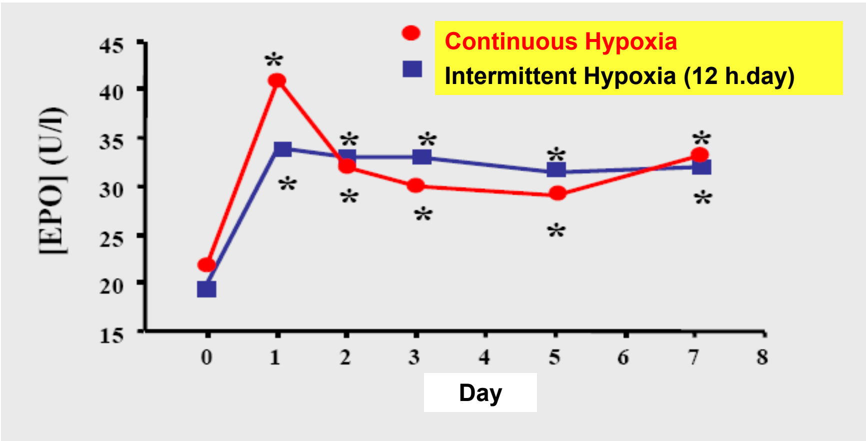
LHTL - EPO secretion at 2500 m



(Koistinen et al., 2000)

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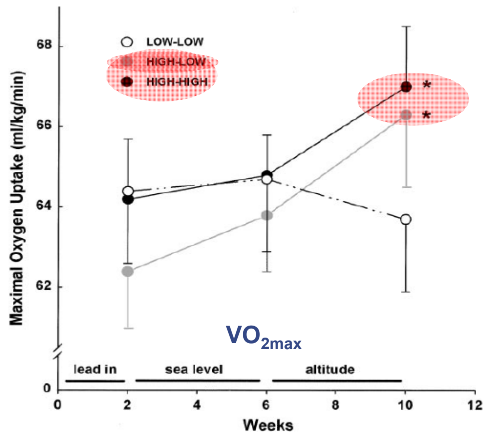
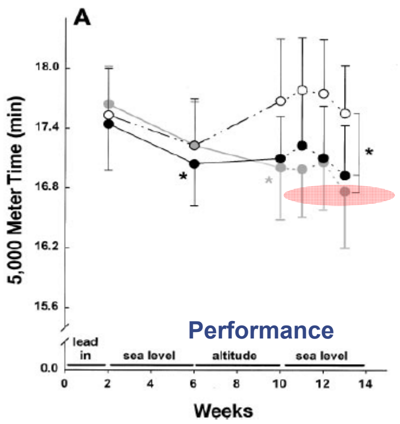
LHTL - Increased VO_{2max} / Improved performance





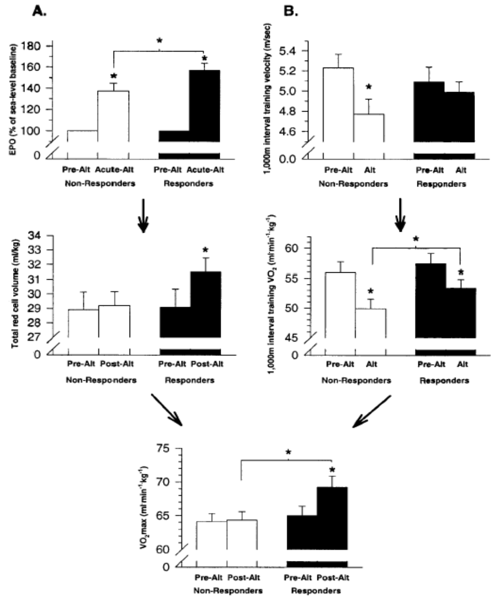
(Levine & Stray-Gundersen, 1997)

EPO

RCV

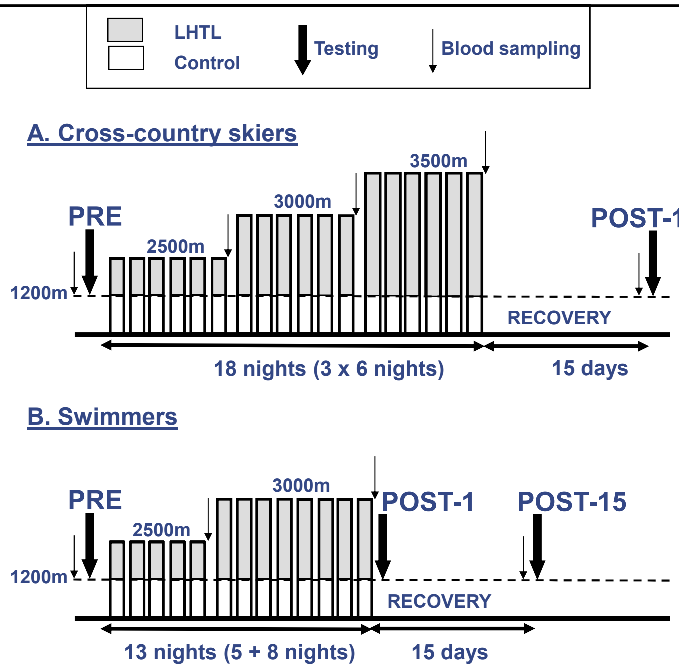
Velocity IT

VO_2 IT



(Levine & Stray-Gundersen, 1997)

VO_{2max}



C. Runners

Id. 18 nights (6 at 2500 + + 12 at 3000)

Multicentric project - IOC

	group	pre- test	post-test1	post-test2
$\dot{V}O_{2max}$ (ml.min^{-1}.kg^{-1})	hypoxic	60,71 ± 4,42	64,95 ± 5,90**	61,32 ± 5,54
	control	59,91 ± 6,27	62,31 ± 6,06*	60,10 ± 5,80
MAP (w)	hypoxic	303 ± 67	315 ± 54**	322 ± 72**
	control	286 ± 40	292 ± 37	291 ± 42#
performance (%)	hypoxic	0	1,80 ± 2,40*	3,40 ± 3,80**
	control	0	1,00 ± 2,80	2,50 ± 3,10**

Small 'additive effect' of LHTL on performance enhancement confirmed. These studies confirm the results of Levine where L training was performed at 1250 m. Delayed effect observed with LHTL (?)

NS difference in VO_{2max} increase.

Return to sea-level values after two weeks.

	group	pre- test	post-test1	post-test2
$\dot{V}O_{2obla}$ (ml.min^{-1}.kg^{-1})	hypoxic	44,66 ± 4,99		48,74 ± 6,91**
	control	47,17 ± 6,16		48,44 ± 5,63
P_{obla} (w)	hypoxic	225 ± 44		248 ± 57***
	control	224 ± 29		228 ± 27
EC (%)	hypoxic	0	0.69±8.93	-5.48±11.36 *
	control	0	0.22±6.79	-5.88±10.47 *
EC_{bic} (VO^2.w^{-1})	hypoxic	16.29 ± 1.80		15.69 ± 2.37*
	control	15.88 ± 3.28		15.45 ± 3.10
EC_{bic} (%)	hypoxic	0		-3.73±8.48*
	control	0		-2.10±9.79

Sub-maximal intensity parameters appear more changed by the LHTL method.

Obla is more increased with LHTL.

Delayed additive effect on economy.

« LHTL : living high-training low »

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Comments :

Great differences observed between the three experiments:

Increased efficiency from swimmers to runners in term of performance enhancement by LHTL by:

Limiting H to 3000 m (XC and runners)

Introductory period at 2500 m (tbc)

« LHTL : living high-training low »

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Increased efficiency by:

Decreasing the overall load (runners)

		W1	W 2	W 3	Post-1	Post-2
Cross-country skiers	LHTL	1856 ± 374	1606 ± 254	1384± 387**	1025 ± 131	1183 ± 119
	C	1598 ± 319	1581 ± 238	1299 ± 352*	894 ± 405	1114 ± 498
Swimmers	LHTL	2831 ± 430	2432 ± 511		1694 ± 162	1662 ± 324
	C	2897 ± 170	2568 ± 216		1800 ± 94	1671 ± 102
Runners	LHTL	499 ± 147	461 ± 104	590 ± 196	423 ± 138	497 ± 81
	C	602 ± 148	540 ± 137	473 ± 192	541 ± 227	478 ± 120

Maintaining the >VT2 loads (swimmers and runners)

	<VT1	VT1-VT2	VT2-MAP	>MAP	Strength Speed
Cross-country skiers	77%	17%	0%	1%	5%
Swimmers	57%	28%	6%	7%	2%
Runners	66%	18%	7%	6%	3%
TOTAL	**70%**	**18%**	**5%**	**5%**	**3%**

LHTL - Improved economy

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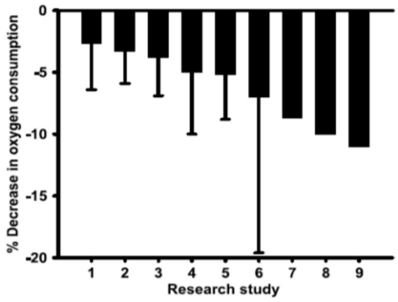

Reported decrease in oxygen consumption during submaximal exercise following LHTL (Gore et al., 2007)

LHTL

Why ?

Augmented red cell volume vs non-hematological factors
- Economy *(Schmitt et al., 2006)*
- Muscle buffering capacity *(Gore et al., 2001)*
- Hypoxic ventilatory response *(Townsend et al., 2002)*

Performance increase by 1-3% vs. similar sea-level training.

How ?

Altitude : 2200 – 2500 m for erythropoietic effect (terrestrial)
Up to 3000 m for non-hematological factors *(Brugniaux et al. 2006)*
Duration :
4 wks for inducing accelerated erythropoiesis *(Ge et al., 2002)*
2 wks enough for non-hematological factors *(Gore et al., 2001)*
Hypoxic daily dose :
Beyond 16 h.day for erythropoietic effect *(Wilber, 2007)*
Shorter (?) for non-hematological changes.
Hypothesis that LHTL in HH more efficient than in NH.

For Who ?

When ?

All (? for top-elite endurance athletes with high RCV)
Prior the major competitions

LHTL

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International Olympic Committee consensus statement on thermoregulatory and altitude challenges for high-level athletes

MF Bergeron,[1,2] R Bahr,[3] P Bärtsch,[4] L Bourdon,[5] JAL Calbet,[6] KH Carlsen,[7–9] O Castagna,[5] J González-Alonso,[10] C Lundby,[11] RJ Maughan,[12] G Millet,[13] M Mountjoy,[14–16] S Racinais,[17] P Rasmussen,[11,18] DG Singh,[19–21] AW Subudhi,[22] AJ Young,[23] T Soligard,[24] L Engebretsen[24]

In elite runners LHTL has been suggested to increase performance.

Thus, although the general recommendations for LHTL (>2000 m>12 h/day) may increase the performance of lower-end athletes, this is not necessarily the case for higher level athletes.

The absence of a positive response could be related to the already high RCV values of these athletes

Advanced : Living high – Training low interspersed

Side effect of LHTL : decrease in Na^+-K^+ ATPase activity

Detrimental, especially in the exercises inducing impairments in excitation-contraction coupling properties like high-intensity intermittent sports

To reverse this detrimental effect :

Alternate nights in hypoxia and nights in normoxia*; i.e.* for example, 5-nights LHTL interspersed with 2-nights in normoxia *(Aughey et al., 2006).*

Improved LHTL method : LHTLi (LHTL interspersed).

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Intermittent Hypoxia

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Intermittent hypoxia

2 different methods:

1) IHE
= Providing hypoxia at rest
= Intermittent Hypoxic Exposure (IHE)
→ To stimulate altitude acclimatization

2) IHT
= Providing hypoxia during exercise
→ To enhance the training stimulus

(Levine, 2002)

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Intermittent Hypoxic Exposure

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IHE - Equipments

Rebreathing devices:

Efficiency of IHE ?

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In studies with control groups, IHE does not induce any substantial change in hematological parameters or in endurance performance

Personal opinion:

IHE (by definition NH) is useful as complement

Pre-acclimatization

Maintenance of LHTH, LHTL and LHTLH adaptations

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Intermittent Hypoxic Training

IHT - Equipments

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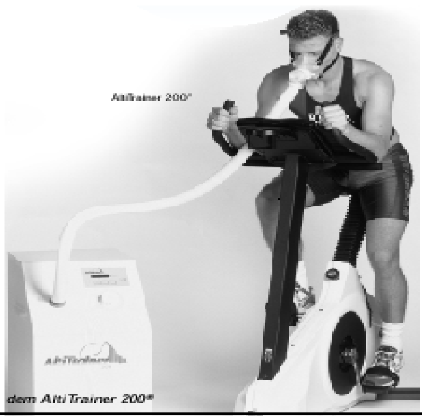
Altitrainer 200®: Altitude chamber



IHT and IHIT- Training at pVO_{2max}

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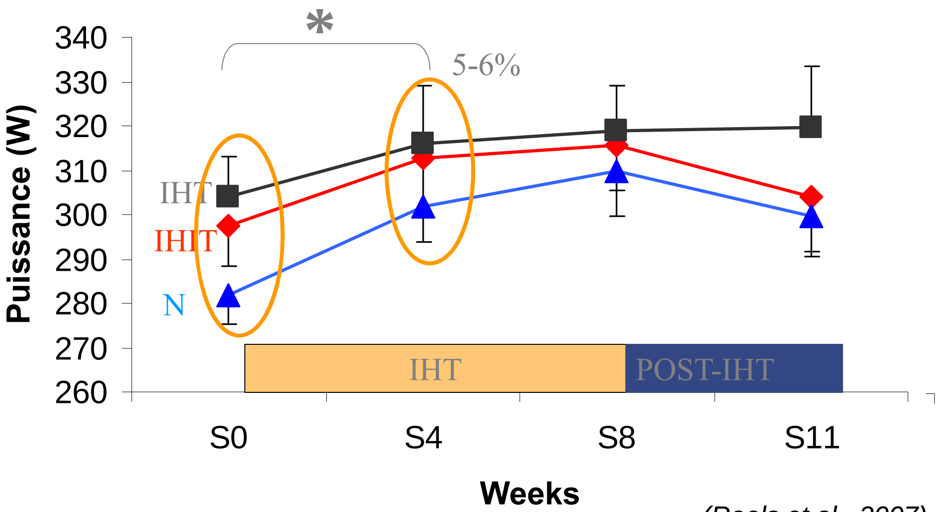
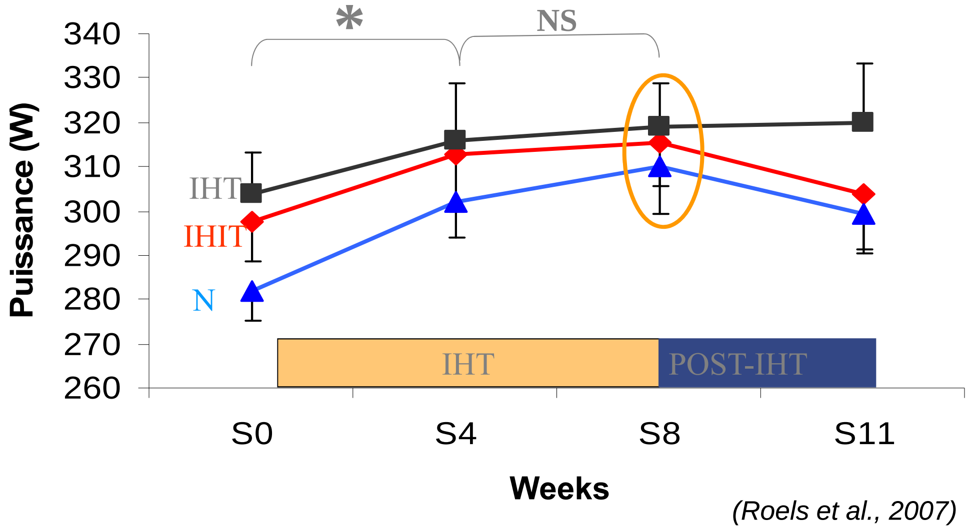
7 wks with 2 sessions.wk. IHT or IHIT at pVO_{2max}. Altitude = 3000 m



(Roels et al., 2007)

IHT and IHIT- Training at pVO_{2max}

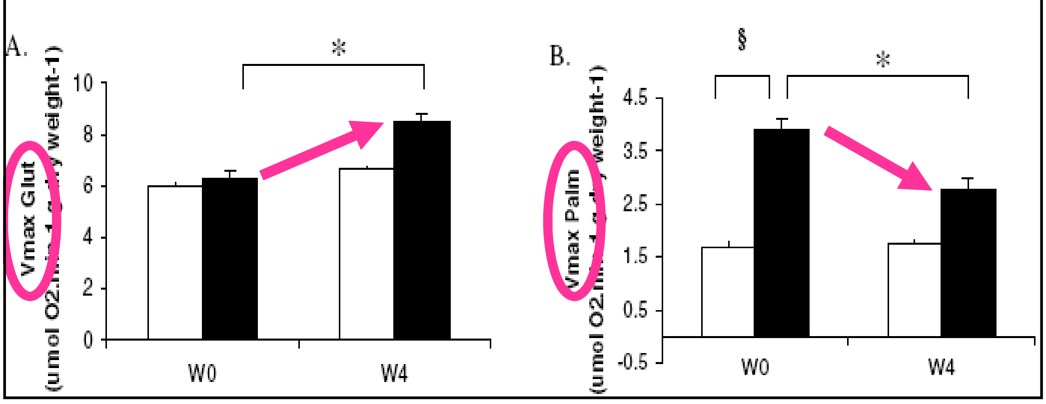
7 wks with 2 sessions.wk. IHT or IHIT at pVO_{2max}. Altitude = 3000 m



(Roels et al., 2007)

- **Muscular adaptations** *(Roels et al, 2008)*

	W0		W4	
	Nor	H	Nor	H
VO_{2max}(ml·kg[1].min[-1])	58.1 ± 0.8	58.5 ± 0.7	61.0 ± 1.2	58.3 ± 0.6
PPO (W)	341.7 ± 3.5	339.0 ± 0.5	366.3 ± 3.2 *	361.5 ± 4.4 *
HR_{max} (bpm)	190.1 ± 1.1	189.7 ± 1.1	188.3 ± 1.5	189.4 ± 1.0
VE_{max} (L·min[-1])	159.9 ± 2.6	154.2 ± 1.4	174.3 ± 2.5	155.0 ± 1.7
RPE_{max}	17.9 ± 0.2	16.4 ± 0.2 §	17.9 ± 0.1	16.9 ± 0.2



IHT: Δ mitochondrial substrate preference

→ ↗ **carbohydrate use (Glutamate)**

→ ↘ **fat oxidation (Palmitate)**

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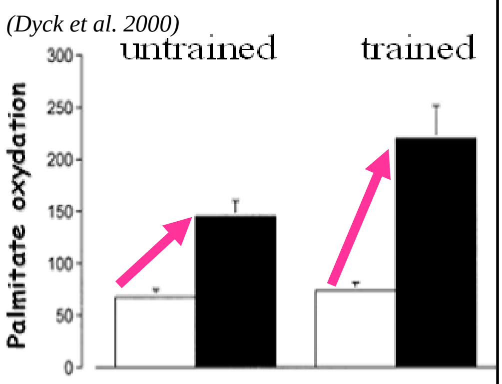
8 weeks of intense endurance training

With training:

Lipid use > carbohydrate use

(Dyck et al, 2000)

Training effect



Living High – Training Low and High, interspersed The optimal combination ?

We proposed to use a modified LHTL by alternating nights high and nights low (LHTLi ; for example, 5-2 or 6-1)

Intense exercise in high altitude stimulates more the muscle adaptations for both aerobic and anaerobic exercises and limit the decrease in power.

Coupling LHTLi and IHT might be the optimal combination

LHTLHi (5 nights at 3000 m and two nights at sea-level with training at sea-level except 2 sessions.wk^{-1} at supra-threshold intensity might be very efficient, especially in team sports (e.g. football).

Inclusion of explosive – agility - sprints

IHT

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Why ?

- Improved buffer capacity
- Increase in mitochondrial efficiency
- Improved pH / lactate regulation
- Metabolic factors of high-intensity intermittent exercises

How ?

Altitude :
2500-3000 m
Training intensity :
High. second ventilatory threshold and/or repeated sprints
Near PPO… not efficient !
Hypoxic dose :
Cycles of 3-6 wks with 2-3 sessions.wk^{-1}

for Who ?
When ?

+ + Intermittent sports : IHT : winter
LHTLH: pre-competition

+ others : pre-acclimatization
maintenance

IHE / IHT

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International Olympic Committee consensus statement on thermoregulatory and altitude challenges for high-level athletes

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In conclusion, the use of intermittent hypoxic exposure (IHE) does not increase sea-level performance and is not recommend. Further research in this area with respect to improving endurance performance does not seem warranted.

In contrast to LHTH and LHTL, is seems safe to conclude that IHT does not increase exercise performance at sea level in endurance athletes any more than simply training at sea level.

We question the fact that team-sport performance could be enhanced with IHT by improving endurance.
Intermittent hypoxic training or repeated-sprints?
Our group recently showed that Repeated Sprint training in hypoxia allowed further enhancement of RS performance than the same training in normoxia (Millet & Faiss, 2012)

Thank you

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Any Questions ?

Few steps beyond..

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La préparation physique.
D. Legallais & G. Millet
2007, Masson

S'entraîner en altitude
G. Millet & L. Schmitt
2011, deBoeck Univ

L'endurance.
Millet G. (ed), 2006
Edition EPS